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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G09G 3/00 — A1

(11) International Publication Number: WO 95/06307

(43) International Publication Date: 2 March 1995 (02.03.95)

(21) International Application Number: PCT/US94/09217

(22) International Filing Date: 15 August 1994 (15.08.94)

(30) Priority Data:
112,116 26 August 1993 (26.08.93) US

(71) Applicant: COPYTELE, INC. [US/US]; 900 Walt Whitman Road, Huntington Station, NY 11746 (US).

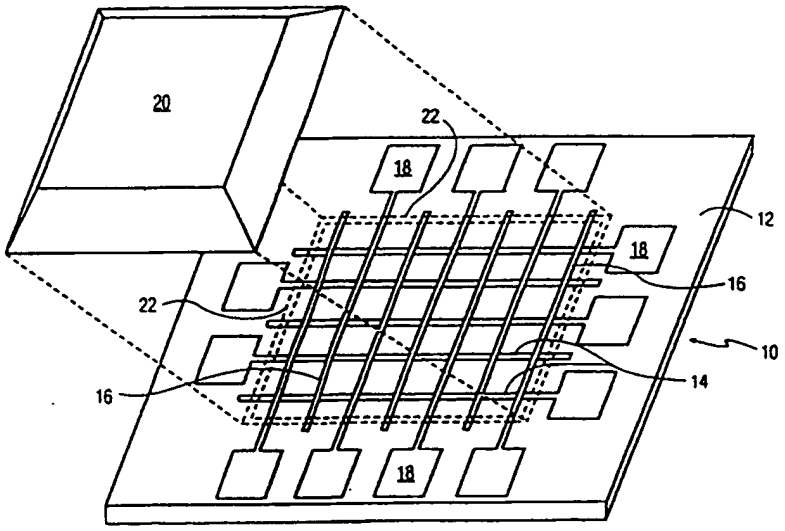
(71)(72) Applicants and Inventors: DISANTO, Frank, J. [US/US]; 27 Par Court, North Hills, NY 11030 (US). KRUSOS, Denis, A. [US/US]; 1 Lloyd Harbor Road, Lloyd Harbor, NY 11743 (US).

(74) Agent: PLEVY, Arthur, L.; Plevy & Associates, P.O. Box 1366, 146 Route 1 North, Edison, NJ 08818-1366 (US).

(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: ELECTROPHORETIC DISPLAY HAVING REDUCED WRITING TIME



(57) Abstract

An electrophoretic display (10) is provided which enables an image to be displayed by selectively energizing intersecting grid (16) and cathode (14) lines each indicative of a pixel and varying the bias between the lines to cause suspended pigment particles to migrate to an anode (20) and away from the energized pixels. Selected intersections of grid (16) and cathode (14) lines indicative of pixels are energized with a set of voltages during a fixed time interval, thereby causing an image to be displayed thereon. The time interval selected is less than the time required to completely remove the pigment particles from the pixels and the image is sequentially enhanced by rewriting at least some of the pixels with the set of voltages at least once. This permits a readable image to be produced much more rapidly and also provides incrementally darker pixels in the image as additional pigment particles are moved from selected intersections during subsequent energizing intervals.

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"ELECTROPHORETIC DISPLAY HAVING REDUCED WRITING TIME"

BACKGROUND ART

Electrophoretic displays (EPIDS) are now well known. A variety of display types and features are taught in several patents issued in the names of the inventors herein, Frank J. DiSanto and Denis A. Krusos and assigned to the assignee herein, Copytele, Inc. of Huntington Station, New York. For example, U.S. Patent Nos. 4,655,897 and 4,732,830, each entitled **ELECTROPHORETIC DISPLAY PANELS AND ASSOCIATED METHODS** describe the basic operation and construction of an electrophoretic display. U.S. Patent No. 4,742,345, entitled **ELECTROPHORETIC DISPLAY PANELS AND METHODS THEREFOR**, describes a display having improved alignment and contrast. Many other patents regarding such displays are also assigned to Copytele, Inc.

The display panels shown in the above-mentioned patents operate upon the same basic principle, viz., if a suspension of electrically charged pigment particles in a dielectric fluid is subjected to an applied electrostatic field, the pigment particles will migrate through the fluid in response to the electrostatic field. Given a substantially homogeneous suspension of particles having a pigment color different from that of the dielectric fluid, if the applied electrostatic field is localized it will cause a visually observable localized pigment particle migration. The localized pigment particle migration results either in a localized area of concentration or rarefaction of particles depending upon the polarity and direction of the electrostatic field and the charge on the pigment particles.

The electrophoretic display apparatus taught in the foregoing U.S. Patents are "triode-type" displays having a plurality of independent, parallel, cathode row conductor elements or "lines" deposited in the horizontal on one surface of a glass viewing screen. A layer of insulating photoresist material deposited over the cathode elements and photoetched down to the cathode elements to yield a plurality of insulator strips positioned at right angles to the cathode elements, forms the substrate for a plurality of independent, parallel column or grid conductor elements or "lines" running in the vertical direction. A glass cap member forms a fluid-tight seal with the viewing window along the cap's peripheral edge for containing the fluid suspension and also acts as a substrate for an anode plate deposited on the interior flat surface of the cap. When the cap is in place, the anode surface is in spaced parallel relation to both the cathode elements and the grid elements. Given a specific particulate suspension, the sign of the electrostatic charge which will attract and repel the pigment particles will be known. The cathode element voltage, the anode voltage, and the grid element voltage can then be ascertained such that when a particular voltage is applied to the cathode and another voltage is applied to the grid, the area proximate their intersection will assume a net charge sufficient to attract or repel pigment particles in suspension in the dielectric fluid. Since numerous cathode and grid lines are employed, there are numerous discrete intersection points which can be controlled by varying the voltage on the cathode and grid elements to cause localized visible regions of pigment concentration and rarefaction. Essentially then, the operating voltages on both cathode and grid must be able to assume at least two states corresponding to a logical one and a logical zero. Logical one for the cathode may either correspond to attraction or repulsion of pigment. Typically, the cathode and grid voltages are selected such that only

when both are a logical one at a particular intersection point, will a sufficient electrostatic field be present at the intersection relative to the anode to cause the writing of a visual bit of information on the display through migration of pigment particles. The bit may be erased, e.g., upon a reversal of polarity and a logical zero-zero state occurring at the intersection coordinated with an erase voltage gradient between anode and cathode. In this manner, digitized data can be displayed on the electrophoretic display.

Besides the triode-type display, the applicant's herein have proposed a variety of EPID structures for utilizing the electrophoretic effect. For example, an alternative EPID construction is described in Application No. 07/345,825, now U.S. Patent No. 5,053,763, entitled **DUAL ANODE FLAT PANEL ELECTROPHORETIC DISPLAY APPARATUS**, which relates to an electrophoretic display in which the cathode/grid matrix as found in triode-type displays is overlayed by a plurality of independent, separately addressable "local" anode lines. The local anode lines are deposited upon and aligned with the grid lines and are insulated therefrom by interstitial lines of photoresist. The local anode lines are in addition to the "remote" anode, which is the layer deposited upon the anode faceplate or cap as in triode displays. The dual anode structure aforesaid provides enhanced operation by eliminating unwanted variations in display brightness between frames, increasing the speed of the display and decreasing the anode voltage required during Write and Hold cycles, all as explained therein.

In general, it can be noted that a variety of EPID configurations have been proposed by the prior art. It has, however, been a problem in regard to such displays to provide grey scale capability. Grey scale capability is a well known term of art and has been utilized for example in regard to the description of television receivers and various other types of data presentations

such as in facsimile and so on. In U.S. Pat. No. 4,833,464, entitled **ELECTROPHORETIC INFORMATION DISPLAY (EPID) APPARATUS EMPLOYING GREY SCALE CAPABILITY**, there is disclosed an EPID which utilizes a timing generator to produce a series of divided clock signals each having a selected duration of time corresponding to a desired grey scale level. In a first sequence, all dark pixels associated with the entire display are written into at the same time by addressing the X Y grid matrix with a first set of voltages. During subsequent sequences, incrementally shorter voltage applications are used to write increasingly lighter grey pixels associated with the display. The display disclosed therein, while representing an advance over prior art displays which lack grey scale capability, is fairly complex as it requires special timing circuitry.

It is therefore an object of the present invention to provide an electrophoretic information display apparatus which provides grey scale capability, which is of reduced complexity, and which is reliable to operate.

DISCLOSURE OF THE INVENTION

An apparatus for operating an electrophoretic information display with grey scale capability has a plurality of pixel areas each accessible by an X-Y addressing format and each indicative of a given display content at that associated display area. The display comprises means for sequentially applying an electric field across selected pixel areas during a series of equal time intervals, each interval being less than the time necessary to completely remove pigment particles associated with the selected pixel areas therefrom. In this manner, incrementally darker pixels are provided after each successive time interval with the darkest pixels being obtained when all of the pigment particles are removed from corresponding intersections. Thus, a grey scale image is

obtained by re-applying the electric field only to pixel areas which are not of the desired shade after a previous interval.

A method of providing grey scale capability for an electrophoretic information display comprises the steps of applying an electrical field across selected intersections for a fixed interval of time less than that required to completely remove the particles therefrom, thereby causing an image having pixels of a first shade to be formed thereon and applying in a second applying step an electrical field across at least some of said selected intersections for said fixed interval, thereby causing an image having pixels of a second shade darker than said first shade to be formed thereon.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a rear perspective view of an electrophoretic display panel employed with the present invention; and

FIG. 2 is a detailed block diagram depicting an apparatus employed with an electrophoretic display and capable of grey scale operation.

BEST MODE FOR CARRYING OUT THE INVENTION

With reference now to FIG. 1, there is shown the rear side of an electrophoretic display panel 10 as exemplified by U.S. Patent No. 4,742,345 to DiSanto et al., this patent being incorporated herein by reference for showing the general construction and components of an electrophoretic display panel. The panel 10 includes a faceplate typically formed from glass which serves as a substrate upon which is deposited a plurality of independent, electrically conductive cathode members 14 (horizontal rows) using conventional deposition and etching techniques. It is preferred that the cathode members 14 be composed of Indium Tin Oxide (ITO) as set forth in U.S. Patent No.

4,742,345. A plurality of independent grid conductor members 16 are superposed in the horizontal over the cathode members 14 and are insulated therefrom by an interstitial photoresist layer (not shown). The grid members 16 may be formed by coating the photoresist layer with a metal, such as nickel, using sputtering techniques or the like and then selectively masking and etching to yield the intersecting but insulated configuration shown in FIG. 1. Each cathode and grid member 14, 16 terminates at one end of a contact pad 18 or is otherwise adapted to permit connection to display driver circuitry, which circuitry will be described later. An anode cap 20 is sealably affixed to the faceplate 12 and over the cathode and grid members 14 and 16 to form an envelope for containing the dielectric fluid/pigment particle suspension. The anode cap 20 is formed from an insulating material, such as glass, and has an inner surface coating of conductor material to form the anode. Thus by applying voltages to the cathode and grid members 14 and 16 and the anode 20, suspended pigment particles in the dielectric fluid can be made to accumulate near, or disperse from, the intersections of selected cathode and grid members 14 and 16 to translate these voltages into a visible display.

The discrete cathode and grid members 14 and 16 of the electrophoretic display 10 can assume a variety of voltages during operation for controlling the display operations or erase, hold and write at the numerous points of intersection defining a cathode/grid matrix. A workable panel would have a large number of intersections, e.g., 2,200 X 1,700 or a total of 3,740,000 separately addressable intersection points. For ease of illustration, however, a small set of intersections are shown in FIG. 1 and only a single intersection is depicted in the remaining figures. The dimensions of the respective elements have also been greatly enlarged for illustration and are not necessarily in proportion to an actual operational device. Representative illustrations of

electrophoretic displays, their components and electrical circuitry can be seen by referring to U.S. Patent Nos. 4,742,345 and 4,772,820, each being awarded to the inventors herein and which are incorporated by reference herein.

As one can readily ascertain upon reference to the previously cited patents, the pigment at the intersections of selected rows and columns is forced out of wells associated therewith (not shown) by selectively applying voltages to the rows and columns, thereby exposing the dye solution and making such intersections dark. The removal of the pigment from the wells is not instantaneous but requires a period of time, which depends upon the dimensions of the display, the applied voltages, and the properties of the suspension. Applying a potential for too short a period of time to a grid and cathode line intersection results in incomplete removal of pigment from the well at that intersection. Accordingly, a pixel intensity which is less than full black may be obtained by utilizing a scan time which is less than the scan time required to completely remove the pigment from the wells. This essentially is the basis of the present application and such techniques for accomplishing this will be further described.

Referring to FIG. 2, there is shown a top view of a typical X-Y matrix consisting of cathode lines which are arranged in the horizontal plane and grid lines which are perpendicular to the cathode lines and insulated therefrom. Thus, there are shown in FIG. 2 four cathode lines designated 22, 24, 26, and N. It is, of course, understood that the number of cathode lines in the Y direction may consist of hundreds of thousands, depending upon the size of the display. As indicated, insulated from the cathode lines and perpendicular thereto, there are also shown four grid lines, 28, 30, 32, and X. It should also be understood that there can be many more grid lines associated with a typical display.

As seen in FIG. 2, each cathode line has a suitable driving amplifier circuit shown in modular form and indicated by reference numerals 36, 38, 40, and 42. In like manner, each grid line has a suitable driving amplifier referenced by modules 44, 46, 48, and 50. The driver amplifiers are fabricated by typical integrated circuit techniques and may, for example, be CMOS devices, all of which are well known and many of which are available as conventional integrated circuit chips.

As in the case of prior art EPID displays, the display of the present invention can typically be operated in an erase mode, a hold mode, or a writing mode. In the erase mode, the anode electrode, which is not shown in FIG. 2, is placed at a negative potential while the cathodes as lines 22-N are operated at a positive potential. In this mode, the grid lines as 28 to X are operated at a negative potential. In the hold mode, the anode is positive while the cathodes are held positive and the grids are again at low potential. As one can understand from the above, the cathode operates between zero and positive voltages. The grid operates between low and high voltages.

In the write mode, the anode is held positive while cathode lines which are being written are placed at zero potential while non-writing cathodes are placed at positive potential. This is the same potential employed in the hold mode. In this manner, the writing grids are operated at high potential. Thus, based on the X-Y matrix, one can produce any alpha numeric character.

As seen from FIG. 2, the Y driving amplifiers are coupled to a Y address module 52. Essentially, the address module 52 is a well known component and consists of various conventional decoding devices and may include buffer registers and so on for the storage of data for introduction to the various cathode lines associated with the display 10. In a similar manner, the X driving amplifiers are coupled to an X address module 54 which module

operates to provide X information for the X-Y intersections provided by the display.

As indicated earlier, pixel intensities of less than full black can be obtained by utilizing a scan time which is less than the scan time required to completely remove the pigment from the wells. In accordance with the present invention, therefore, a number of sequential complete image scans are required before the displayed image will appear as a fully written picture. A readable image may also be produced using very fast scan times and by repeated scans can be enhanced sequentially to attain full black.

According to the present invention, both faster writing times and grey scale operation are made possible by selecting a scan time according to the equation:

$$t_s = T_d/n \qquad (1)$$

where t_s is the fixed duration for which a voltage is applied to a given pixel intersection or scan time, n is the number of shades of grey desired, and T_d is the minimum amount of time required to remove pigment particles from the pixel location and thus fully write that pixel full black. By way of illustration, if the total time needed to write a display pixel full black is 80 milliseconds, then it is possible to achieve eight shades of grey by selecting a scan time of 10 milliseconds. It will, however, be appreciated that any scan time which is less than the minimum full black scan time may be utilized in accordance with the present invention. Thus, using the same example, if only two shades are desired, it is contemplated that a scan time of 60 milliseconds may be used even though the total scan sequence of 120 milliseconds exceeds the minimum scan time.

FIG. 2 illustrates one possible arrangement for operating the display of the present invention in accordance with a keyboard mode. As

shown in FIG. 2, information is input by keyboard 56 into the memory 60 of computer microprocessor 58. A pulse generator 62, which is coupled to X-address module 54 and Y-address module 52, provides write pulses of a predetermined fraction of the total write time T_d, which predetermined fraction is selected as discussed above to achieve the desired number of grey scale levels. In accordance with the illustrative embodiment, one or more key strokes may be utilized to define ASCII codes which correspond to particular grey scale values. These codes are utilized by a line select grey code module 64, which may be part of microprocessor 58, to selectively address those lines of the display containing characters which are to appear darker than the other characters.

The character data is converted into a bit stream which is received by shift registers within the X and Y address modules. All portions of the image are written during this first image scan. However, those portions of the image which are to be at the lightest shade of grey are written only during this first image scan. Selected cathode lines, as 22, 24, 26, and N, are placed at the enable voltage level by the cathode driving amplifiers, which driving amplifiers are fed row information by the Y address module of the microprocessor. The column information for row 22 is fed into a shift register within X address module 54, the output of the shift register feeding the grid driving amplifiers. When a clock signal has shifted enough bits for one character width, a signal is sent to the memory telling it to present the code for the next character to the input of the character generator. This process continues until all of the column information for cathode line 22 has entered the grid driving amplifiers by way of the shift register. This process is repeated for all the cathode lines such as 24, 26, and N until all characters of the display are written.

As indicated above, the total number of scans is determined as a function of the number of grey scale levels desired. Accordingly, only those characters of the display which are at the second lightest shade of grey or darker, as determined by the microprocessor within the character generator, are now written during a second scan. Accordingly, in this second scan the line select grey code module 64 feeds the row and column information of the display into the shift registers of the X and Y address modules, but, as already indicated, the row and column information corresponding to those pixels at the lightest shade of grey is omitted. Thus, by operation of the line select module 64, only those rows and columns which contain characters of the second lightest shade or darker are energized by the pulse generator. Sequential scanning procedure is continued for shades three, four, five, six, and seven. Only those portions of the image which are black are scanned on all eight sequential scans.

Hence, in this manner as one will readily understand, all pixels of the display can be written into during a first scan, with only successively darker pixels being written into during subsequent scans. Accordingly, not only does the present invention make it possible to achieve grey scale operation, but it also permits a readable image to be displayed in significantly less time than is taught by prior art EPIDs. It should thus be apparent to those skilled in the art that the above-described techniques and associated apparatus lends itself to many alternate embodiments. For example, instead of operating the display in a keyboard mode, the display may be adapted to receive data from a typical telephone line or other transmission media using an analog to digital converter and digital signal pixel generator (not shown). Each of the aforementioned components are commercially available and well known in the prior art, all of which are deemed to be encompassed within the spirit and scope of the specification and the claims as appended.

CLAIMS:

1. Apparatus for driving an electrophoretic display in a write mode, which display is of the type having a plurality of electrically conductive grid lines insulated from a plurality of electrically conductive cathode lines with said grid and cathode lines positioned perpendicular to one another to provide an X-Y matrix, and said display having an anode electrode and an insulating fluid containing particles of at least one color pigment in suspension disposed between said anode electrode and said lines, said display enabling an image to be displayed by selectively accessing intersecting grid and cathode lines each indicative of a pixel and varying the bias between said lines to cause said particles to migrate to said anode for each selected intersection, the improvement in connection therewith comprising:

means for energizing selected intersections of grid and cathode lines indicative of pixels with a set of voltages during a fixed time interval, thereby causing an image to be displayed thereon, wherein said time interval is less than the time required to completely remove said pigment particles from said pixels and wherein said energizing means is adapted to sequentially enhance said image by rewriting at least some of said selected intersections with said set of voltages at least once.

2. The apparatus according to claim 1, wherein said display is adapted to provide a plurality of grey scale values such that the number of times said energizing means writes a darkest pixel is equal to the number of grey scale levels provided by said display.

3. The apparatus according to claim 1, wherein said fixed interval is equal to the total amount of time needed to completely remove said pigment particles divided by the number of pixel shades desired for the display.

4. The apparatus according to claim 1, wherein said energizing means includes electric field applying means coupled to electrodes associated with said cathode and grid lines.

5. The apparatus according to claim 1, further including keyboard means coupled to said energizing means operative to generate alphanumeric characters for presenting X-Y data to said display.

6. The apparatus according to claim 1, wherein said energizing means includes microprocessor means for selecting pixels of said image to be written and re-written.

7. A method of providing grey scale capability for an electrophoretic information display of the type employing an insulating fluid containing particles of at least one color pigment in suspension disposed between an anode electrode and intersecting electrically conductive grid and cathode lines, each intersection indicative of a pixel, wherein a pixel is fully written by applying a potential to intersections and thereby remove pigment particles therefrom, comprising the steps of:

energizing selected pixels for a fixed interval of time less than that required to completely remove said particles therefrom, thereby causing an image having pixels of a first shade to be displayed; and

energizing in a second energizing at least some of said selected pixels for said fixed interval, thereby causing an image having pixels of a second shade darker than said first shade to be displayed.

8. The method of claim 7, further including the step of selecting the duration of said interval by dividing the minimum time needed to completely remove pigment particles from said intersections by the number of shades to be displayed.

9. The method of claim 7, further including sequentially energizing said display to provide incrementally darker pixels at some of said selected intersections until all of said pigment particles are removed therefrom.

10. The method of claim 7, further including the step of generating alphanumeric characters for presenting X-Y data to said display.

11. The method of claim 10, wherein said characters are generated by a keyboard during said generating step.

12. An apparatus for operating an electrophoretic information display with grey scale capability, said display being of the type having a plurality of pixel areas each accessible by an X-Y addressing format and each indicative of a given display content at that associated display area comprising:

means for sequentially applying an electric field across selected pixel areas during a series of equal intervals, each interval being less than the time necessary to completely remove pigment particles associated with said selected pixel areas therefrom, wherein incrementally darker pixels are provided after each successive interval until all of said pigment particles are removed from at least one of said selected pixel areas, wherein a grey scale image is obtained by applying said electric field only to pixel areas which are not of the desired shade after a previous interval.

13. The apparatus according to claim 12, wherein said energizing means includes means for driving X lines associated with said display and means for driving Y lines associated with said display with intersections between X and Y lines indicative of said pixel areas.

14. The apparatus according to claim 12, wherein said display is of the type employing X lines deposited on a glass substrate and fabricated from indium tin oxide (ITO) at a thickness such that said line pattern is transparent and having insulated therefrom a Y line pattern also fabricated from ITO with the intersection at each X and Y line associated with a particle well and indicative of a pixel area for said display.

15. The apparatus according to claim 12, further including microprocessor means for determining the number of intervals during which said electric field is to be applied to each pixel.

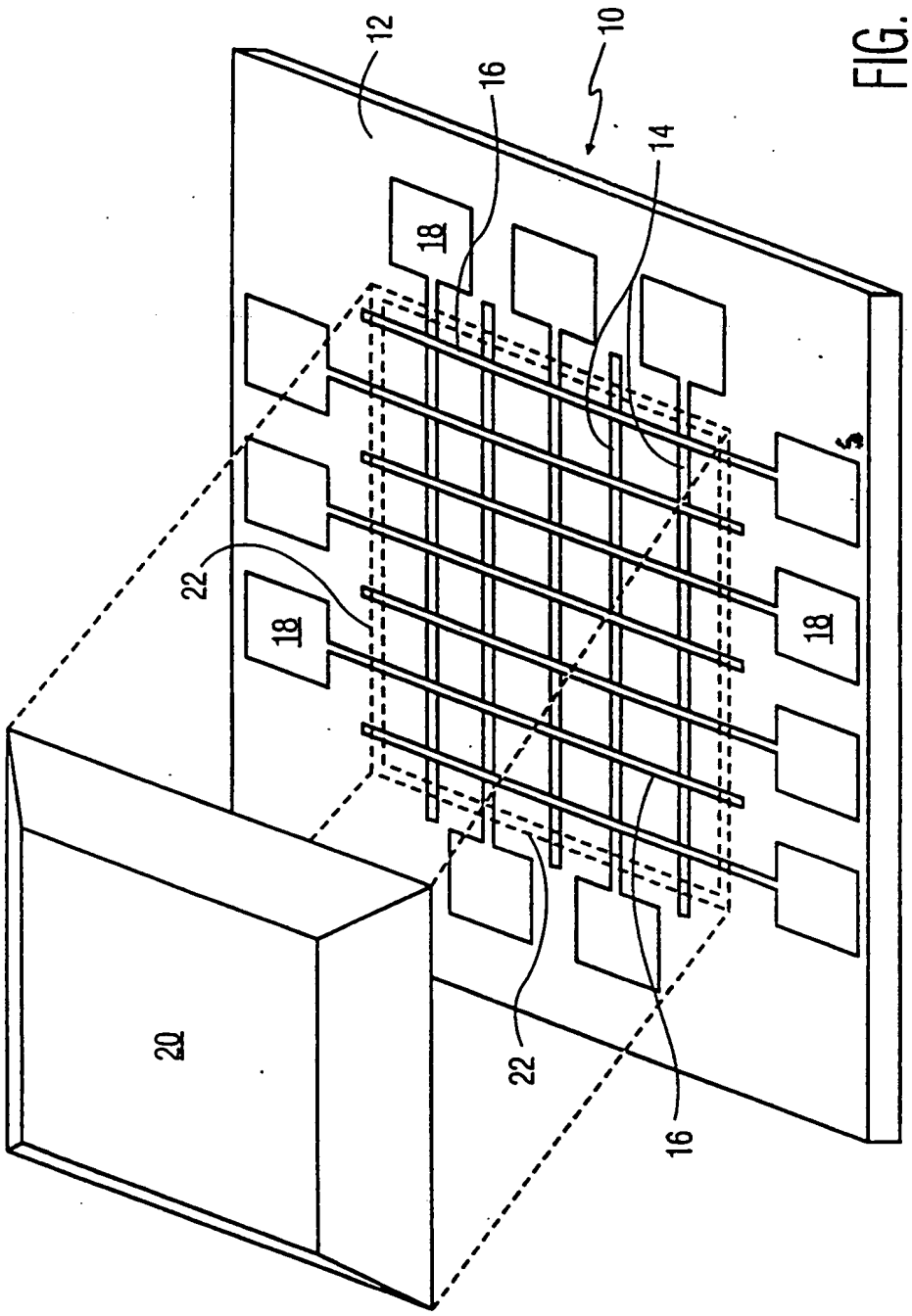

FIG. 1

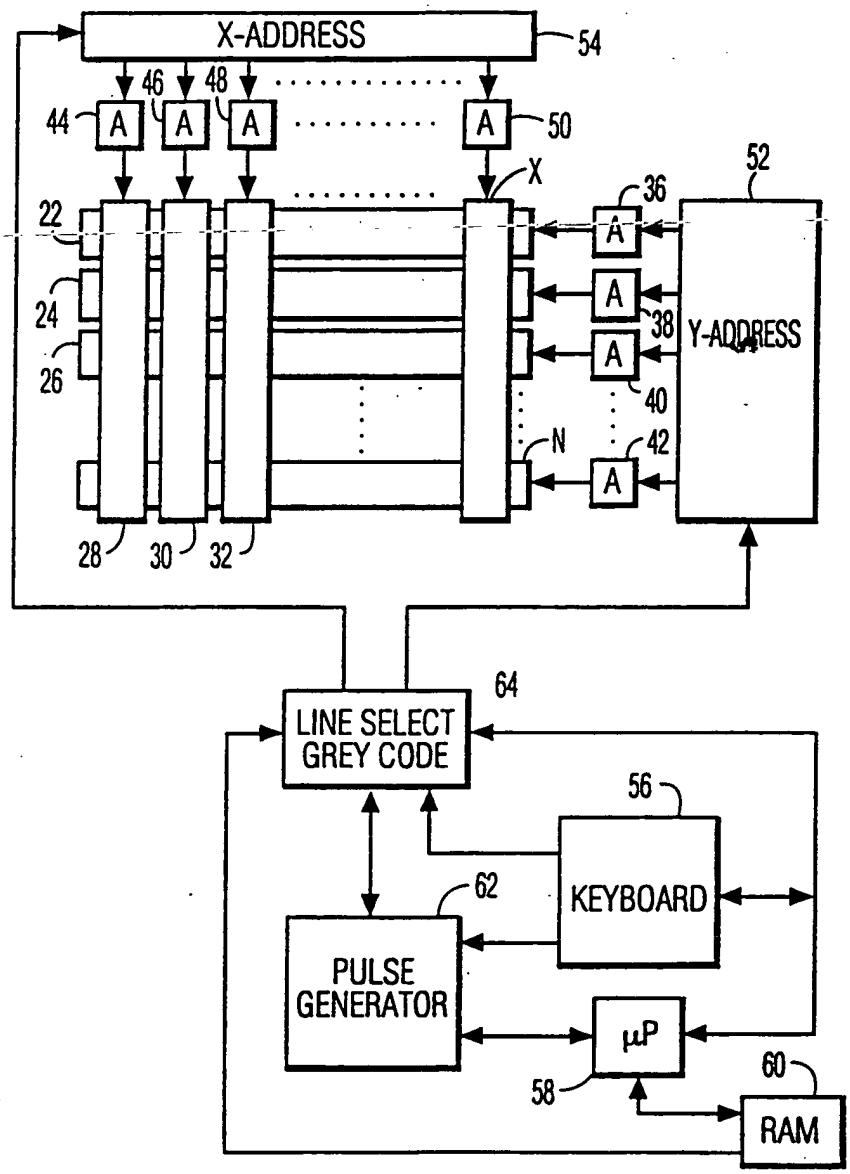
X-ADDRESS
54
46
48
44
A
50
X
52
36
22
24
26
38
Y-ADDRESS
40
N
42
28
30
32
64
LINE SELECT
GREY CODE
56
KEYBOARD
62
PULSE
GENERATOR
μP
60
58
RAM

FIG. 2

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G09G 3/00

US CL :345/107

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 345/89, 107, 147, 148, 149, 150

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,833,464 (DI SANTO et al.) 23 May 1989, col. 3, lines 63-68; col. 4, lines 13-16; col. 6, lines 11-31 and col. 9, lines 54-64.	1-15
Y	US, A, 5,023,603 (WAKIMOTO et al.) 11 June 1991, col. 1, lines 24-55 and fig. 1.	1-15
A	US, A, 3,612,758 (EVANS et al.) 12 October 1971, see entire document.	1-15
A	US, A, 4,827,255 (ISHII) 02 May 1989, see entire document.	1-15
A	US, A, 4,947,157 (DI SANTO et al.) 07 August 1990, see entire document.	1-15

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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